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FINAL REPORT

MACHINABILITY INDEX

OF

AIRFRAME MATERIALS

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FOREWORD

The purpose of this report is to present under one cover the latest available machining data on materials used in airframe manufacture.

The information presented herein is a compilation of data on cutting speeds, feeds, tool materials and tool geometry for typical machining operations on most types or classes of work materials.

Section I includes a machinability index showing the ease or difficulty, expressed in percent, to be expected in machining various materials when compared with B-1112 steel having a machinability rating of 100%.

Section II relates suggested cutting speeds, feed rates, tool material, tool geometry and pertinent remarks for machining various work materials.

The information contained herein is not intended to represent minimum or maximum limits for each situation. It is, however, felt to be adequate for initial set-ups providing good sound basic machining practices are employed.

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INTRODUCTION TO SECTION I

MACHINABILITY INDEX

The machinability index given for each alloy, with the exception of titanium alloys,[(1)] is based upon B-1112 cold drawn steel = 100%. The machinability of an alloy will vary with the variations in hardness and microstructure. However, the index numbers give the general relative machinability of the alloy and can be used in determining proper cutting speeds.

Section I contains information designed to assist Engineering design personnel in selecting, where possible, the material with the highest machinability rating which will result in the least manufacturing difficulty.

The index includes materials most generally used in current aircraft production and were chosen from the Convair Materials Manual. Also included are materials with less extensive current applications, but of greater importance to the design of future air vehicles.

Index ratings are given for the various "Brinell" hardness of materials to show its relationship to machinability, using H.S.S. tools.

Machine power requirements are also shown to further emphasize the machining characteristics of individual materials.

Values given for the index ratings were compiled from available data. Sources for this data are listed in the Bibliography.

(1) Based on B-1113 C.D. = 100%.

Table 1

MACHINABILITY INDEX

ALUMINUM ALLOYS

Type	Brinell Hardness Number	Index Rating	Avg. Unit Power H.P./Cu.In./Min.
2014-T4	105	140	
2024-T	120	150	
3003	40	180	
5052	67	190	0.12 -0.20
6061-T	65	190	
6063-T	65	190	
7075-T	150	120	
7178-T			

COPPER ALLOYS

Type	Brinell Hardness Number	Index Rating	Avg. Unit Power H.P./Cu.In./Min.
Naval Brass	180	70	0.51
Brass (Half-Hard)	125	140	0.30
Phosphor Bronze (Half-Hard)	172	63	0.33
Aluminum Bronze	166	42	0.60
Manganese Bronze	185		0.56

MAGNESIUM ALLOYS

Type	Brinell Hardness Number	Index Rating	Avg. Unit Power H.P./Cu.In./Min.
AZ31B			
AZ61A			
AZ80A	32 to 68	200	.09 to .10
MIA			
ZK60A			

MARTENSITIC LOW ALLOY STEELS

Type	Brinell Hardness Number	Index Rating	Avg. Unit Power H.P./Cu.In./Min.
4130	187	65	0.69
4130	400	40	1.10
4140	187	65	0.69
4140	400	40	1.10
4340	297	45	1.20
4340	550	10	1.80
Hy-Tuff	310	40	1.20
Hy-Tuff	475	20	1.50
*H-11	187	44	0.74
H-11	550	5-10	2.03

*5% Chrome, Hot Work Die Steel

Table 2

MACHINABILITY INDEX (Continued)

AUSTENITIC STAINLESS STEEL
(non-hardenable by heat-treat)

Type	Brinell Hardness Number	Index Rating	Avg. Unit Power H.P./Cu.In./Min.
302	180	50	0.72
303	174	67	0.66
304	163	40	
316	200	35	
321/347	180	46	0.76

MARTENSITIC STAINLESS STEEL
(hardenable by heat-treat)

410	166	55	0.75
410	370		1.10
431	180	45	
431	370		

PRECIPITATION HARDENING STAINLESS STEEL

17-4PH	363	65	
17-4PH	481	25	
17-7PH	229	20	1.00
17-7PH	375	16	1.10
AM-350	250	40	0.86
AM-350	484	15	1.20
AM-355	250	40	0.86
AM-355	480	15	1.20

***HIGH STRENGTH STEELS**

Super Tricent	180	40	
Super Tricent	575	5-10	
Potomac M	200	45	
Potomac M	570	5-10	
Thermold J	180	40	
Thermold J	575	10	

* Machinability is similar to H-11, Refer to Tables 10 & 12 for Machining Criteria.

Table 3

MACHINABILITY INDEX (Continued)

HIGH TEMPERATURE ALLOYS

Type	Brinell Hardness Number	Index Rating	Avg.Unit Power H.P./Cu.In./Min.
A-286	321	27	0.82
N-155		15	
19-9DL	228	40	
Discaloy	350	30	
Timken 16-25-6		31	1.10
Refractaloy -26	311	20	1.30
Incoloy 901		20	
NICKEL BASED ALLOYS			
K-Monel	240	35	0.80
KR-Monel	240	45	0.61
Inconel X	363	15	0.90
Nimonic 90	293	10	1.10
Udimet 500	302	9	
Inconel 700	302	8	1.40
713	363	6	1.06
R-235	320	8	1.26
Rene 41	380	6	
Hastelloy X	220	20	
Hastelloy 56	250	17	
COBALT BASED ALLOYS			
S.-816	290	9	1.25
G.E. 1570		9	1.30
H.S.-25 (L 605)	230	12	1.11
(1) TITANIUM (PURE AND ALLOYED)			
Commercial Pure (2)	160-200	38	0.76
2.5 AL-16V	200-375		
4 AL-3MO-1V	285-389	24	0.93
6AL - 4V	285-340	26	0.87
8 MN	273-321	13	1.15
A-110AT	285-321	29	0.81
B-120 VCA	270-375		
RS-140	311-388		

(2) Cutting Speeds can be increased approximately 50%

(1) Based on B-1113 = 100

INTRODUCTION TO SECTION II

MACHINING CRITERIA

The data contained in Section II was obtained by reviewing and analyzing all articles listed in the Bibliography, as well as from past AMR projects.

It is intended to provide general machining criteria for persons concerned, and to establish a compilation of useful information on some of the lesser known or unfamiliar materials.

Description of abbreviated tool geometry is detailed in Appendix B of this report.

While no specific recommendations as to tool geometry, tool material, cutting speeds or feeds are made, the data contained in this Section is considered to be accurate and reliable for reasonable tool life and prevention of excessive tooling expenses.

Aluminum Alloys

2014-T4

2024

3003

5052

6061-T

6063-T

7075-T6

7178-T6

TABLE 4
MACHINING CRITERIA FOR
ALUMINUM ALLOYS

Operation	Tool Material	Tool Geometry	Depth of Cut (In.)	Cutting (5) Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-2	SR: 6° BR: 0° SRF: 5 SCEA: 15°	to .50	to 8,000	.005 to .020 in. per rev.	
Face Milling	H.S.S. M-2	AR: 25° RR: 10° CR: .06 R.RF:10°	to .38 (4)	to 2,000	.008 to .015 in. per tooth	
Face Milling	Carbide C-2	AR: 0° to 10° RR: 0° to 10° CR: .06 R.RF:8°	to .38 (4)	to 10,000	.008 to .020 in. per tooth	
End Milling	H.S.S. M-2	Helix: 30° RR: 8° CR: .06 R.RF:8°	to 1. (2)	to 1,000	.004 to (6) .008 in. per tooth	
End Milling	Carbide C-2	Helix: 30° RR: 5° CR: .06 R.RF:8°	to 1. (2)	to 10,000	.004 to (6) .008 in. per tooth	
Side Milling	H.S.S. M-2	AR: 25° RR: 18° CR: .06 R.RF:10°	to 1.	to 2,000	.005 to .015 in. per tooth	
Side Milling	Carbide C-2	AR: 10° RR: 10° CR: .06 R.RF:8°	to 1.	to 10,000	.005 to .015 in. per tooth	

TABLE 5
MACHINING CRITERIA FOR
ALUMINUM ALLOYS (continued)

Operation	Tool Material	Tool Geometry	Depth of Cut (In.)	Cutting (5) Speed (sfm)	Feed	Remarks
Drilling	H.S.S.	PA: 118° L RF: 15°	(3)	to 1,000	1/8-1/4 dia-.001-.003 1/4-1/2 dia-.004-.007 1/2 - 1.dia-.007-.015	
Tapping	H.S.S.	2 or 3 flutes spiral point 15° hook		to 130		
Reaming	H.S.S.	R.H. spiral		2/3 rds of drilling speeds	2 to 3 times drilling feeds	

(6) For end mills under 1/2" reduce feed to .001 - .003 I.P.T.

(5) Within H.P. limitation of machines

(4) Three-fourths of cutter diameter = cutting width

(3) Based on two diameter drill depths

(2) Depth of cut not to exceed diameter

(1) Based on insert tooling

Copper Alloys

Naval Brass

Brass (Half Hand)

Phosphor Bronze (Half Hand)

Aluminum Bronze

Manganese Bronze

TABLE 6
MACHINING CRITERIA FOR
COPPER ALLOYS

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning[1]	Carbide C-2	SR: 6° BR: 0° SRF: 5° SCEA: 15°	.250	to 1,000	.006 to .010 in. per rev.	
Face Milling	H.S.S. M-2	AR: 25° RR: 10° CR: .06 R.RF:10°	.250[4]	to 500	.008 to .020 in. per tooth	
Face Milling	Carbide C-2	AR: 0° to 10° RR: 0° to 10° CR: .06 R.RF:8°	.250[4]	to 1,000	.007 to .012 in. per tooth	
End Milling	H.S.S. M-2	Helix: 30° RR: 8° CR: .06 R.RF:6°	[3]	to 325	.003 to[5] .008 in. per tooth	
End Milling	Carbide C-2	Helix: 30° RR: 5° CR: .06 R.RF:8°	[3]	to 450	.003 to[6] .007 in. per tooth	
Side Milling	H.S.S. M-2	AR: 25° RR: 18° CR: .06 R.RF:10°	.250	to 375	.005 to .012 in. per tooth	
Side Milling	Carbide C-2	AR: 10° RR: 10° CR. .06 R.RF:8°	.250	to 550	.005 to .012 in. per tooth	

TABLE 7
MACHINING CRITERIA FOR COPPER ALLOYS (continued)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Drilling	H.S.S.	PA: 118° to 140° LRF:15°	③	to 150	1/8-1/4--.001-.003 1/4-1/2--.004-.007 1/2-1 --.007-.015	
Tapping	H.S.S.	2 or 3 flutes spiral point 15° hook		30-50		
Reaming	H.S.S.					

⑤ End mills under 1/2" - .0005 -.003 i.p.t.
④ Three-fourths of cutter diameter = cutting width
③ Based on two-diameter drill depths
② Depth of cut not to exceed cutter diameter
① Based on insert tooling

Magnesium Alloys

A231B

A261A

A280A

M1A

ZK60A

TABLE 8
MACHINING CRITERIA FOR
MAGNESIUM ALLOYS

Operation	Material	Geometry	Depth of Cut(In.)	Cutting ① Speed (sfm)	Feed	Remarks
Turning	Carbide C-2	SR: 10° to 12° BR: 0° SRF: 7° to 10° SCEA: 15°	to .50	to 5,000	.010 to in. per rev.	Keen edged tools should always be used
Turning	H.S.S. M-2	SR: 15° to 22° BR: 0° SRF: 10° SCEA: 15°	to .50	to 2,000	.008 to .045 in. per rev.	"
Face Milling	Carbide C-2	AR: 15° RR: 10° LA: 5° R.RF:10°	to ② .50	to 9,000	.005 to .025 in. per tooth	Use coarse ③ tooth cutter
Face Milling	H.S.S. M-2	AR: 20° RR: 18° LA: 5° R.RF:10°	to ② .50	to 3,000	.005 to .025 in. per tooth	" ③
End Milling	H.S.S. M-2	Helix: 30° RR: 8° CR: .06 R.RF:10°	to .50	to 2,000	.003 to .015 in. per tooth	
Side Milling	Carbide C-2	AR: 15° RR: 10° CR: .06 R.RF:10°	to .50	to 5,000	.005 to .025	Use coarse ③ tooth cutter

TABLE 9
MACHINING CRITERIA FOR
MAGNESIUM ALLOYS(continued)

Operation	Material	Geometry	Depth of Cut(In.)	Cutting ① Speed (sfm)	Feed	Remarks
Side Milling	H.S.S. M-2	AR: 20° RR: 18° CR: .06 R.RF:10°	to .50	to 2,000	.005 to .025 in. per tooth	Use coarse ③ tooth cutter
Drilling	H.S.S.	PA: 118° LRF:15° Helix: 40° to 50°		to 1,000	to 1/4" - .004-.030 to 1/2" -.012 -.030 to 1" - .015-.030	
Tapping	H.S.S.	2 or 3 flute high hook (15° to 18°) aluminum spiral point		30-50		
Reaming	H.S.S.	Straight or Right Hand Spiral	1/32 on diameter	to 400	Same as drilling feeds	Use 4 flutes up to 1" diameter and 6 flutes over 1"

③ No. of teeth may be one-third to one-half number normally used
② Three-fourths of cutter diameter = cutting width
① Within H.P. limitations of machine

Martensitic Low Alloy Steels

4130

4140

4340

Hy Tuff

H-11

High Strength Steels

Super Tricent

Potomac M.

Thermold J

TABLE 10
MACHINING CRITERIA FOR MARTENSITIC LOW ALLOY STEELS (90,000 to 160,000 PSI)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning 1	Carbide C-6	SR: -7° BR: -7° SRF: 7° SCEA: 15°	.200	350 - 450	.005 to .010 in. per rev.	
Face Milling 1	Carbide C-6	AR: -7° RR: -7° CA: 45° x .06 R.RF: 7°	.250	450 - 600 3	.005 to .010 in. per tooth	
Face Milling	H.S.S. M-2	AR: 10° RR: 10° CR: .06 R.RF: 6°	.300	60 - 110	.004 to .012 in. per tooth	
End Milling	Carbide C-6	Helix: 15° RR: 5° CR: .06 R.RF: 7°	250	300 - 400	.003 to 4 .007 in. per tooth	right hand helix
End Milling	H.S.S. M-2	Helix: 30° RR: 5° CR: .06 R.RF 6°	.300	60 - 110	.003 4 to .008 in. per tooth	
Side Milling 1	Carbide C-6	AR: -7° RR: -7° CR: .06 R.RF 7°	.250	300 - 450	.005 to .010 in. per tooth	

TABLE 11
MACHINING CRITERIA FOR
MARTENSITIC LOW ALLOY STEELS (continued)
(90,000 to 160,000 PSI)

Operation	Tool Material	Tool Geometry	Depth of Cut (In.)	Cutting Speed (sfm)	Feed	Remarks
Side Milling	H.S.S. M-2	AR: 10° RR: 10° CR: .06 R.RF: 6°	.300	60 - 110	.005 to .015 in. per tooth	
Drilling	H.S.S. M-2	PA: 135 LRF: 7° split point	2	30 - 50	1/8-1/4--.001-.003 1/4-1/2--.005-.005 1/2-1--.010-.020	
Tapping	H.S.S.	2 flute spiral point		10 - 30		
Reaming	H.S.S.	Straight or right hand		2/3rds speed of drilling	2 to 3 times feed of drilling	

4 End Mills under 1/2" - .0002 - .003 i.p.t.

3 Three-fourths of cutter diameter = cutting width

2 Based on two diameter drill depths

1 Based on insert tooling

TABLE 12
MACHINING CRITERIA FOR MARTENSITIC LOW ALLOY STEELS
(180,000 to 220,000 psi)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-6	S.R.: -7° B.R: -7° S.RF: 7° S.C.E.A:15°	.120	200 - 325	.004 to .008 in. per rev.	
Face Milling (1)	Carbide C-6	A.R: -7° R.R: -7° L.A: 5° R.RF: 7°	.120 (3)	250 - 375	.004 to .007 in. per tooth	
Face Milling	H.S.S. M-2 or M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 5°	.100	25 - 40	.003 to .006 in. per tooth	
End Milling	Carbide C-6	Helix: 15° R.R: 5° C.R: .06 R.RF: 6°	.120	175 - 250	.003 to (4) .005 in. per tooth	Use shortest possible flute length for max. rigidity
End Milling	H.S.S. T-15	Helix: 30° R.R: 5° C.R: .06 R.RF: 5°	.120	30 - 50	.004 to (4) .007 in. per tooth	Use shortest possible flute length for max. rigidity
Side Milling (1)	Carbide C-6	A.R: -7° R.R: -7° C.R: .06 R.RF: 7°	.150	225 - 325	.004 to .008 in. per tooth	Climb mill

TABLE 13
MACHINING CRITERIA FOR
MARTENSITIC LOW ALLOY STEELS (continued)
(180,000 to 220,000 psi)

Operation	Tool Material	Tool Geometry	Depth of Cut (In.)	Cutting Speed (sfm)	Feed	Remarks
Side Milling	H.S.S. M-2 M-3	A.R: 10° R.R: 10° C.R: 06 R.RF: 5°	.100	25 - 40	.004 to .007 in. per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 135° L.RF: 7° split point	2	15 - 35	1/8-1/4- .001-.003 1/4-1/2- .002-.008 1/2-1 - .007-.012	
Tapping	H.S.S.	3 flute spiral point		10 - 20		Nitride finish on tap
Reaming		Straight or right hand spiral		2/3rds speed of drilling	2 to 3 times feed of drilling	

4 End mills under 5/8" .0002 - 003 i.p.t.

3 Three-fourths of cutter diameter = cutting width

2 Based on two diameter drill depths

1 Based on insert tooling

TABLE 14
MACHINING CRITERIA FOR
MARTENSITIC LOW ALLOY STEELS
(240,000 to 280,000 psi)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning ①	Carbide C-3	S.R. -7° B.R: -7° S.RF: 7° SCEA: 15°	.100	100 - 150	.005 to .009 in. per rev.	
Face ① Milling	Carbide C-2	A.R: -7° R.R: -7° L.A: 5° R.RF: 7°	.080	120 - 150 ③	.004 to .007 in. per tooth	
Face Milling	H.S.S.	←——— NOT RECOMMENDED ———→				
End Milling	Carbide C-2	Helix: 25° R.R:0°-3° C.R: .06 R.RF: 6°	.080	100 - 150	.002 to ④ .006 in. per tooth	L.H. spiral R.H. cut
End Milling	H.S.S.	←——— NOT RECOMMENDED ———→				
Side ① Milling	Carbide C-5	A.R: -7° R.R: -7° C.R: .06 R.RF: 7°	.080	120 - 160	.003 to .006 in. per tooth	Climb mill
Side Milling	H.S.S.	←——— NOT RECOMMENDED ———→				
Drilling	H.S.S. M-33	P.A: 135° L.RF: 7° split point	②	8 - 15	1/8-1/4 - .001-.003 1/4-1/2 - .003-.005 1/2-1 - .006-.012	
Tapping	H.S.S.	2 flute spiral point 8 to 15° hook		8 - 12		Nitride finish on tap
Reaming	Carbide					

④ End mills under 5/8" - .0002 - .002" i.p.t.   ② Based on two diameter drill depths
③ Three-fourths of cutter diameter   ① Based on insert tooling

Austenitic Stainless Steels

302

303

304

316

321/347

TABLE 15
MACHINING CRITERIA FOR
AUSTENETIC STAINLESS STEELS

Operation	Tool Material	Tool Geometry	Depth of Cut (in.)	Cutting Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-2	S.R: -7° to 6° B.R: -7° to 0° S.RF: 6° SCEA: 15°	.200	150 - 250	.005 to .015 in. per rev.	
Turning	Cast Alloy	S.R: 10° to 18° B.R: 0° S.RF: 7° SCEA: 15°	.200	125 - 170	.007 to .020 in. per rev.	
Face Milling (1)	Carbide C-2	A.R: 0° R.R: 0° L.A: 30° R.RF. 6°	.150 (3)	180 - 230	.005 to .010 in. per tooth	
Face Milling (1)	Cast Alloy	A.R: 0° R.R: 0° L.A: 30° R.RF: 6°	.200 (3)	140 - 170	.007 to .015 in. per tooth	
Face Milling	H.S.S. M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 7°	.200 (3)	60 - 90	.005 to .015 in. per tooth	
End Milling	Carbide C-2	Helix: 25° R.R: 5° C.R: .06 R.RF: 7°	.100	150 - 200	.003 to (4) .007 in. per tooth	Use shortest possible flute length for max. rigidity
End Milling	Cast Alloy	Helix: 25° R.R: 5° C.R: .06 R.RF: 7°	.150	140 - 170	.005 to (4) .010 in. per tooth	Use shortest possible flute length for max. rigidity

TABLE 16
MACHINING CRITERIA FOR
AUSTENETIC STAINLESS STEELS (continued)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
End Milling	H.S.S. M-3	Helix: 30° R.R: 8° C.A: 6° R.RF: 8°	.200	60 - 90	.003 to (4) .007 in. per tooth	Use shortest possible flute length for max. rigidity
Side Milling	Carbide C-2	A.R: 10° R.R: 5° C.R: .06 R.RF: 6°	.250	175 - 200	.005 to .010 in. per tooth	Climb mill
Side Milling	H.S.S. M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 8°	.250	60 - 90	.004 to .008 in. per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 135° L.RF: 8° split point	(2)	25 - 40	1/8-1/4-.001-.003 1/4-1/2-.004-.007 1/2-1 -.007-.015	Use stub length drills for max. rigidity
Tapping	H.S.S. M-10	3 flutes Int. Thd. spiral point 15° hook		12 - 15		
Reaming	H.S.S.	Straight or right hand spiral		2/3rds of drilling speeds	2 to 3 times drilling speeds	

(4) End mills under 1/2" - .0005 to .002 i.p.t.

(3) Three-fourths of cutter diameter

(2) Based on two diameter drill depths

(1) Based on insert tooling

Martensitic Stainless Steels

410

431

TABLE 17
MACHINING CRITERIA FOR
MARTENSITIC STAINLESS STEELS
(Annealed Condition 160 - 180 BHN and Heat-Treated Condition 360 - 400 BHN

Operation	Tool Material (4)	Tool Geometry	Depth of Cut (In.)	Cutting Speed (sfm) (5)	Feed	Remarks
Turning (1)	Carbide	S.R: -7° B.R: -7° S.RF: 7° SCEA: 15°	.100	125 - 175 225 - 350	.005 to .015 in. per rev.	
Turning	Cast Alloy	S.R: 12° to 18° B.R: 0° S.RF: 7° SCEA: 15°	.200	90 - 120 130 - 180	.005 to .020 in. per rev.	
Face Milling (1)	Carbide	A.R: 0° R.R: 0° L.A: 30° R.RF: 7°	.150 (3)	140 - 180 190 - 250	.005 to .010 in. per tooth	
Face Milling (1)	Cast Alloy	A.R: 0° R.R: 0° L.A: 30° R.RF: 7°	.200 (3)	100 - 140 120 - 160	.005 to .015 in. per tooth	
Face Milling	H.S.S. M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 8°	.200 (3)	40 - 70 60 - 90	.005 to .015 in. per tooth	
End Milling	Carbide	Helix: 25° R.R: 5° C.R: .06 R.RF: 7°	.100	80 - 120 160 - 220	.003 to (6) .007 in. per tooth	Flute length should be as short as possible for max. rigidity.
End Milling	Cast Alloy	Helix: 25° R.R: 5° C.R: .06 R.RF: 8°	.150	70 - 100 130 - 170	.005 to (6) .010 in. per tooth	Flute length should be as short as possible for max. rigidity.

TABLE 18
MACHINING CRITERIA FOR
MARTENSITIC STAINLESS STEELS (continued)
(Annealed Condition 160 - 180 BHN and Heat-Treated Condition 360 - 400 BHN)

Operation	Tool (4) Material	Tool Geometry	Depth of Cut(In.)	Cutting (5) Speed (sfm)	Feed	Remarks
End Milling	H.S.S. M-3	Helix: 30° R.R: 5° C.R: .06 R.RF: 8°	.200	30 - 50 60 - 90	.003 to (6) .007 in. per tooth	Flute length should be as short as possible for max. rigidity.
Side Milling	Carbide	A.R: 10° R.R: 5° C.R: .06 R.RF: 6°	.250	140 - 180 180 - 260	.005 to .010 in. per tooth	Climb mill
Side Milling	H.S.S. M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 8°	.250	40 - 60 60 - 90	.004 to .008 in. per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 135° L.RF: 8° split point	(2)	25 - 40	1/8-1/4-.001-.003 1/4-1/2-.004-.007 1/2-1 -.007-.015	Use stub length drills whenever possible
Tapping	H.S.S.	3 flute spiral point Int.Thd. 15° hook		10 - 20		
Reaming	H.S.S.	Straight or right hand spiral		2/3rds of drilling speeds	2 to 3 times drilling feeds	

(6) End Mills under 1/2" - .0005 to .002 i.p.t.

(5) Upper column denotes speed range for hardened condition, lower column for annealed condition.

(4) C-2 grade of carbide for heat treat condition
C-6 grade of carbide for annealed condition

(3) Three-fourths of cutter diameter = cutting width

(2) Based on two diameter drill depths

(1) Based on insert tooling

Precipitation Hardening Stainless Steels

17-4PH

17-7PH

AM-350

AM-355

TABLE 19
MACHINING CRITERIA FOR
Precipitation Hardening Stainless Steels

Operation	Tool Material	Tool Geometry		Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning ①	Carbide C-2	S.R: B.R: S.RF: SCEA:	6° 0 5 15	.100	130-180	.005 to .010 in. per rev.	
Turning	Cast Alloy	S.R: B.R: S.RF: SCCA:	15° 0° 5 0°	.100	60-90	.005 to .015 in. per rev.	
Face ① Milling	Carbide C-2	A.R: R.R: L.A: R.RF:	0° 0 30° 7°	.100 ③	90-125	.005 to .010 in. per tooth	
Face ① Milling	Cast Alloy	A.R: R.R: L.A: R.RF:	0 0° 30 8	.100 ③	60-90	.005 to .015 in. per tooth	
Face Milling	H.S.S. T-15	A.R: R.R: L.A: R.RF:	10° 10 30° 8	.060 ③	40-60	.006 to .010 in. per tooth	
End Milling	Carbide C-2	Helix: R.R: C.R: R.RF:	25° 5 .06 7°	.100	70-100	.002 to ④ .0045 in. per tooth	Flute length should be as short as possible for maximum rigidity.
End Milling	Cast Alloy	Helix: R.R: C.R: R.RF:	25° 5° .06 8°	.100	50-70	.003 to ④ .008 in. per tooth	" "
End Milling	H.S.S. T-15	Helix: R.R: C.R: R.RF:	30° 8° .06 12	.100	35-50	.003 to .007 in. per tooth	" "

TABLE 20
MACHINING CRITERIA FOR
Precipitation Hardening Stainless Steels (continued)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Side Milling	Carbide C-2	A.R: 5° R.R: 15° C.R: .06 R.RF: 7°	.100	90-125	.005 to .010 in. per tooth	Climb Mill
Side Milling	H.S.S. M-3	A.R: 10° R.R: 10° C.R: .06 R.RF: 8°	.150	35-55	.004 to .008 in. per tooth	Climb Mill
Drilling	H.S.S. M-33	P.A: 135° L.C: 8° split point	2	10-20	1/8-1/4--.001-003 1/4-1/2--.004-007 1/2-1--.007-015	Use stub length drills whenever possible
Tapping	H.S.S.	3 Flute Spiral Point 15° Hook		5-8		
Reaming	H.S.S.	Straight or right hand spiral		2/3rds of drilling speeds	2 to 3 times drilling feeds	

(4) End mills under 1/2" - .0005 to .002 i.p.t.

(3) Three-fourths of cutter diameter

(2) Based on two diameter drill depths

(1) Based on insert tooling

High Temperature Alloys

A-286
N-155
19-9DL
Discoloy
Timken 16-25-6
Refractoloy-26
Incoloy 901

K-Monel
KR Monel
Inconel X
Nimonil 90
Udimet 500
Inconel 700
713
R-235
Rene 41
Hastelloy X
Hastelloy 56

} Nickel Based Alloys

S 816
G.E. 1570
H.S 25 (L-605)

} Cobalt Based Alloys

Commercial Pure
2.5 AL 16V
4AL-3MO-1V
6AL-4V
MN
A-110 AT
B-120 VCA
RS 140

} Titanium Alloys

TABLE 21
MACHINING CRITERIA FOR

A-286 5
(Solution-Treated and Aged - 321 BHN)

Operation	Tool Material	Tool Geometry		Depth of Cut (in.)	Cutting Speed (sfm)	Feed	Remarks
Turning	Carbide C-7	S.R: B.R: S.RF: SCEA:	-7° -7° 7° 15°	.100	180-260	.005 to .010 in. per rev	Avoid cutter dwell
Face 1 Milling	Cast Alloy	A.R: R.R: L.A: R.RF:	0° 0° 5° 7°	.080 3	40-80	.008 to .015 in. per tooth	Climb mill
End Milling	H.S.S. T-15	Helix: R.R: C.R: R.RF:	30° 7° .06 12°	.060	70-110	.009 to 4 .015 in. per tooth	Climb mill
Side Milling	H.S.S M-2 M-3	A.R: R.R: C.R: R.RF:	10° 10° .06 6°	.060	45-60	.006 to .012 in. per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: L.RF: Split Point	118° 10°	2	25-35	1/8-1/4-.001-.006 1/4-1/2-.006-.009 1/2-1 -.001-.012	Use stub length drills whenever possible
Tapping	H.S.S. M-10	2 Flute Spiral Point			8-12		Nitride finish
Reaming	H.S.S.	Straight or Right Hand Spiral			1/2 of drilling speeds	2 to 3 times drilling speeds	

5 Best machining condition for A-286 is solution treated and aged to 280 BHN

4 End mills under 3/4" - .002-.005 i.p.t.

3 Three-fourths of cutter diameter = cutting width

2 Based on two diameter drill depths

1 Based on insert tooling

TABLE 22
MACHINING CRITERIA FOR
Inconel 700
(Solution - Treated and Aged to 330 BHN)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-2	S.R: 5° B.R: 0° S.RF: 5° SCEA: 15°	.100	60-90	.006 to .011 in. per rev.	Hone cutting edge slightly
Face Milling	H.S.S. T-15	A.R: 10° R.R: 10° L.A: 45° R.RF: 10°	.080 (3)	20-30	.003 to .009 in. per tooth	Climb mill
End Milling	H.S.S. T-15	Helix: 30° R.R: 7° C.R: .03 R. RF: 12°	.060	25-35	.002 to (4) .005 in. per tooth	Climb mill
Side Milling	H.S.S. T-15	A.R: 10° R.R: 10° C.R: .03 R.RF: 10°	.080	20-30	.004 to .009 in. per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 118° L.RF: 7° Split Point	(2)	10-20	1/8-1/4-.001-.002 1/4-1/2-.001-.005 1/2-1 -.005-.009	Use stub length drills whenever possible
Tapping	H.S.S.	2 flute plug spiral point		5-10		
Reaming	H.S.S.	Right hand spiral		1/2 of drilling speeds	2 to 3 times drilling feeds	

(4) End mills under 1/2" - .001 to .003 i.p.t.

(3) Three-fourths of cutter diameter cutting width

(2) Based on two diameter drill depth

(1) Based on insert tooling

TABLE 25
MACHINING CRITERIA FOR
R - 235
(Solution-Treated and Aged to 320 BHN)

Operation	Material	Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning ①	Carbide C-7	S.R: -7 B.R: -7° S.Rf: 7° SCEA: 15	.100	60-80	.006 to .009 in per rev.	Hone cutting edge
Face Milling ①	Carbide C-1	A.R: 0° R.R: 0° C.A: 5° R.Rf: 11	③ .060	30-55	.007 to .008 in per tooth	Climb mill
End Milling	H.S.S. T-15	Helix: 30° R.R: 7° C.R: .06 R.Rf: 6	.060	15-35	.004 ④ to .005 in per tooth	Climb mill
Side Milling	H.S.S. M-2 M-3	A.R: 10° R.R: 10° C.R: .06 R.Rf: 6°	.060	15-25	.005 to .006 in per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 118 L.Rf: 10° Split Point	②	10-15	1/8-1/4-.002-.007 1/4-1/2-.005-.008 1/2-1 -.007-.012	Use stub length drills whenever possible
Tapping	H.S.S.	2 flutes spiral point 8° hook		5-10		
Reaming	H.S.S.	Straight or right hand sprial		1/2 of drilling speeds	2 to 3 times drilling feeds	

④ End mills under 5/8" - .001 to .003 i.p.t.
③ Three-fourths of cutter diameter - cutting width
② Based on two-diameter drill depths
① Based in insert tooling

TABLE 24
MACHINING CRITERIA FOR
RENE 41
(Solution Treated and Aged to 380 BHN)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning ①	Carbide C-2	S.R: 5° B.R: 0° S.Rf: 5° SCEA: 15°	.125	40-70	.005 to .015 in per rev.	Hone cutting edge
Face Milling	H.S.S. T-15	A.R: 29-1/2° R.R: 0° L.A: 35° R.Rf: 7°	.100 ②	15-25	.005 to .012 in per tooth	Climb mill
End Milling	H.S.S. T-15	Helix: 30° R.R: 7° C.A: .06 R.Rf: 15°	.060	20-30	.008 to .010 in per tooth	
Side Milling	←——NO DATA AVAILABLE——→					
Drilling	H.S.S. M-33	P.A: 118° L.Rf: 9° Split Point		4-8	1/8-1/2 - .002- .006 ③	
Tapping	←——NO DATA AVAILABLE——→					
Reaming	←——NO DATA AVAILABLE——→					

③ .0003 - .0005 for each 1/16" of drill diameter
② Three-fourths of cutter diameter = cutting width
① Based on insert tooling

TABLE 25
MACHINING CRITERIA FOR
HASTELLOY X
(Solution Heat-Treated - 250 BNH)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Turning ①	Carbide C-2	SR: 5° BR: 0° SRF: 5° SCEA: 15°	.100	60-80	.009 to .017 in. per rev.	Non cutting edge
Face Milling	Carbide C-1 or C-2	AR: 29 1/2° RR: 0° LA: 35° R.Rf: 7°	.100 ③	60-80	.006 to .012 in. per tooth	Climb mill
End Milling	⟵ NO DATA AVAILABLE ⟶					
Side Milling	⟵ NO DATA AVAILABLE ⟶					
Drilling	H.S.S. M-33	PA: 135° - 140° LRf: 10° Split Point	②	14-21	1/16 - 1/4 - - .005 to .002 1/4 - 3/4 -- .002 to .004	
Tapping	H.S.S.	2 flute plug spiral point		5-10		
Reaming	H.S.S.	Straight or right hand spiral	Max. .010	1/2 of drilling speeds	up to 1.	.006 to .010 in. per rev.

③ Three-fourths of cutter diameter = cutting width
② Based on two-diameter drill depths
① Based on insert tooling

TABLE 26

MACHINING CRITERIA FOR

H.S. - 25 (L-605)

(Solution-Treated 239 BHN)

Operation	Material	Geometry	Depth of Cut (In.)	Cutting Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-7	S.R: 7° B.R: 7° S.Rf: 7 SCEA 15	.100	100-400	.007 to .010 in per rev.	Hone cutting edge
Face (1) Milling	Carbide C-1	A.R: 0° R.R: 0° L.A: 5° R.Rf: 7	.080 (3)	50-80	.005 to .006 in per tooth	Climb mill
End Milling	H.S.S. T-15	Helix: 30° R.R: 7° C.R: .006 R.Rf: 6°	.060	25-40	.005 (4) to .006 in per tooth	
Side Milling	H.S.S. M-2	A.R: 10° R.R: 7 C.R: .006 R.Rf: 6°	.060	25-35	.005 to .006 in per tooth	Climb mill
Drilling	H.S.S. M-33	P.A: 118° L.Rf: 10° Split Point	(2)	20-35		Use stub length drills whenever possible.
Tapping	H.S.S.	2 flutes spiral point 8° hook		5-10		
Reaming	H.S.S.	Straight or right hand spiral		2/3rds of drilling speeds		2 to 3 times drilling speeds

(4) End Mills under 5/8" - .002 to .003 i.p.t.
(3) Three-fourths of cutter diameter = cutting width
(2) Based on two-diameter drill points
(1) Based on Insert Tooling

TABLE 27
MACHINING CRITERIA FOR
Titanium Alloys

Operation	Material	Geometry	Depth of Cut (In.)	Cutting Speed (sfm)	Feed	Remarks
Turning (1)	Carbide C-2	S.R: -7° B.R: -7° S.Rf: 7° SCEA: 15°	.200	125-225	.005 to .012 in per rev.	
Turning	Cast Alloy	S.R: 12° - 18° B.R: 0° S.Rf: 7° SCEA: 15°	.200	80-110	.005 to .015 in per rev.	Preferred when interrupted cuts are involved
Face Milling (1)	Carbide C-2	A.R: 0° R.R: 0° L.A: 30° R.Rf: 7°	.200 (3)	95-125	.004 to .006 in per tooth	
Face Milling	Cast Alloy	A.R: 0° R.R: 0° L.A: 30° R.Rf: 7°	.200 (3)	60-90	.005 to .008 in per tooth	
Face Milling	H.S.S. M-3	A.R: 10° R.R: 10° L.A: 30° R.Rf: 8°	.300 (3)	40-50	.004 to .010 in per tooth	
End Milling	Cast Alloy	Helix: 0° R.R: 0° C.R: .03 R.Rf: 7°	.125	70-100	.007 (4) to .007 in per tooth	
End Milling	H.S.S. M-3	Helix: 30° R.R: 5° C.R: .03 R.Rf: 8°	.125	30-40	.003 to .005 in per tooth	To reduce frictional forces, polished flutes are recommended
Side Milling (1)	Carbide C-2	A.R: 0° R.R: 0° C.R: .03 R.Rf: 7°	.200	95-125	.004 to .006 in per tooth	

TABLE 28
MACHINING CRITERIA FOR
Titanium Alloys (continued)

Operation	Tool Material	Tool Geometry	Depth of Cut(In.)	Cutting Speed (sfm)	Feed	Remarks
Side Milling	H.S.S. M-3	A.R.: 10° R.R.: 10° C.R.: .03 R.RF: 8°	.300	40-50	.004 to .010 in. per tooth	
Drilling	H.S.S. M-33	P.A.: 135° L.RF: 9° Split Point	(2)	20-35	1/8-1/4-.001-.002 1/4-1/2-.001-.007 1/2-1 -.005-.010	Drills should be of Type "C" construction (heavy web)
Tapping	H.S.S.	Int. Thd. spiral point angle: 8° 3 flutes		10-12		Pitch dia. relief should be of the full eccentric type.
Reaming	H.S.S.	Straight or right hand spiral		1/2 of drilling speeds	In general, feeds are same as drilling	If R.H. Spiral is used, grind .015 wide neutral land at corner of reamer.

(4) End Mills under 5/8" - .005 to .002 i.pt.

(3) Three-fourths of cutter diameter cutting width

(2) Based on two diameter drill depths

(1) Based on insert tooling

APPENDIX A

TOOL MATERIALS

1. High Speed Steel
2. Cast Alloy
3. Carbide

High Speed Steel

High Speed Steels are basically divided into two types by the major alloying elements, Molybdenum (designated by the letter "M" as the first character in the symbol such as M-1, etc.) and Tungsten (designated by the letter "T" as the first character in the symbol such as T-1, etc.)

Under these two types come the various analyses according to the presence and percentages of the minor alloying elements. Variations are made for the desired results of hot hardness, abrasion resistance and toughness.

Tungsten and Cobalt increase hot hardness and abrasion resistance of H.S.S. but reduce their toughness. Reducing the Vanadium and Cobalt content reduces hot hardness and abrasion resistance but increases toughness.

Note: See Figure 1 for temperature and hardness relationship of various tool materials.

IDENTIFICATION OF HIGH SPEED STEELS

Type of High Speed Steel	Symbol	Principal Alloying Elements % Molybdenum	Chromium	Vanadium	Tungsten	Cobalt
Moly Tungsten Type	M-1	8	4	1	1-1/2	
	M-2	5	4	2	6	
	M-7	8-3/4	4	2	1-3/4	
Moly Tungsten Vanadium Type	M-3 (Type 1)	6	4	2.4	6	
	M-3 (Type 2)	6	4	3	6	
	M-4	4-1/2	4	4	5-1/2	
Moly Tungsten 1-1/4% Columbium Type	M-8	5	4	1-1/2	5	
Moly Vanadium Type	M-10	8	4	2		
Moly Tungsten Cobalt Type	M-6	5	4	1-1/2	4	12
	M-15	3-1/2	4	5	6-1/2	5
	M-30	8	4	1-1/4	2	5
	M-33	9-3/4	4	1	1-3/4	8-1/4
	M-34	8	4	2	2	8
	M-35	5	4	2	6	5
	M-36	5	4	2	6	8
Moly Cobalt Type (Boron Added)	M-40	8	4	1-1/2		8
Tungsten Type	T-1		4	1	18	
	T-2		4	2	18	
	T-3		4	3	18	
	T-7		4	2	14	
	T-9		4	4	18	
	T-4		4	1	18	5
	T-5		4	2	18	8
	T-6		4-1/2	1-1/2	20	12
	T-8		4	2	14	5
	T-15		4	5	12	5

Cast Alloys

Cast alloy materials are, as the name implies, a cast tool material and usually contain from 35% to 50% Cobalt with lesser amounts of Nickel, Chromium, Tungsten and Vanadium. Good edge strength is retained up to 1200 F with a higher red hardness than high speed steels.

CAST ALLOYS
Principal Alloying Elements %

Type	Cobalt	Chromium	Tungsten	Tantalum or Columbium	Others
Tantung G	47	30	15	5	3
Haynes Stellite 98M-2	38	30	18	--	7.5

Carbide

Carbide tool materials are made in two grades, namely

1. Non-ferrous - Containing only Tungsten Carbides. (Generally applied to operations where abrasion is the prime factor).

2. Steel - Containing Tungsten, Titanium, Tantalum, and Columbium Carbides. (Generally applied to operations where heat is the prime factor).

All commercial carbides contain Cobalt as a binder which holds the Carbide Matrix together. Variations within the carbide material are attributed to: method of manufacture (hydrogen or vacuum sintered), method of pressing, sintering temperature, method of mixing, hardness and percentage of alloying elements used.

Note: See Figure 2 for classifications.

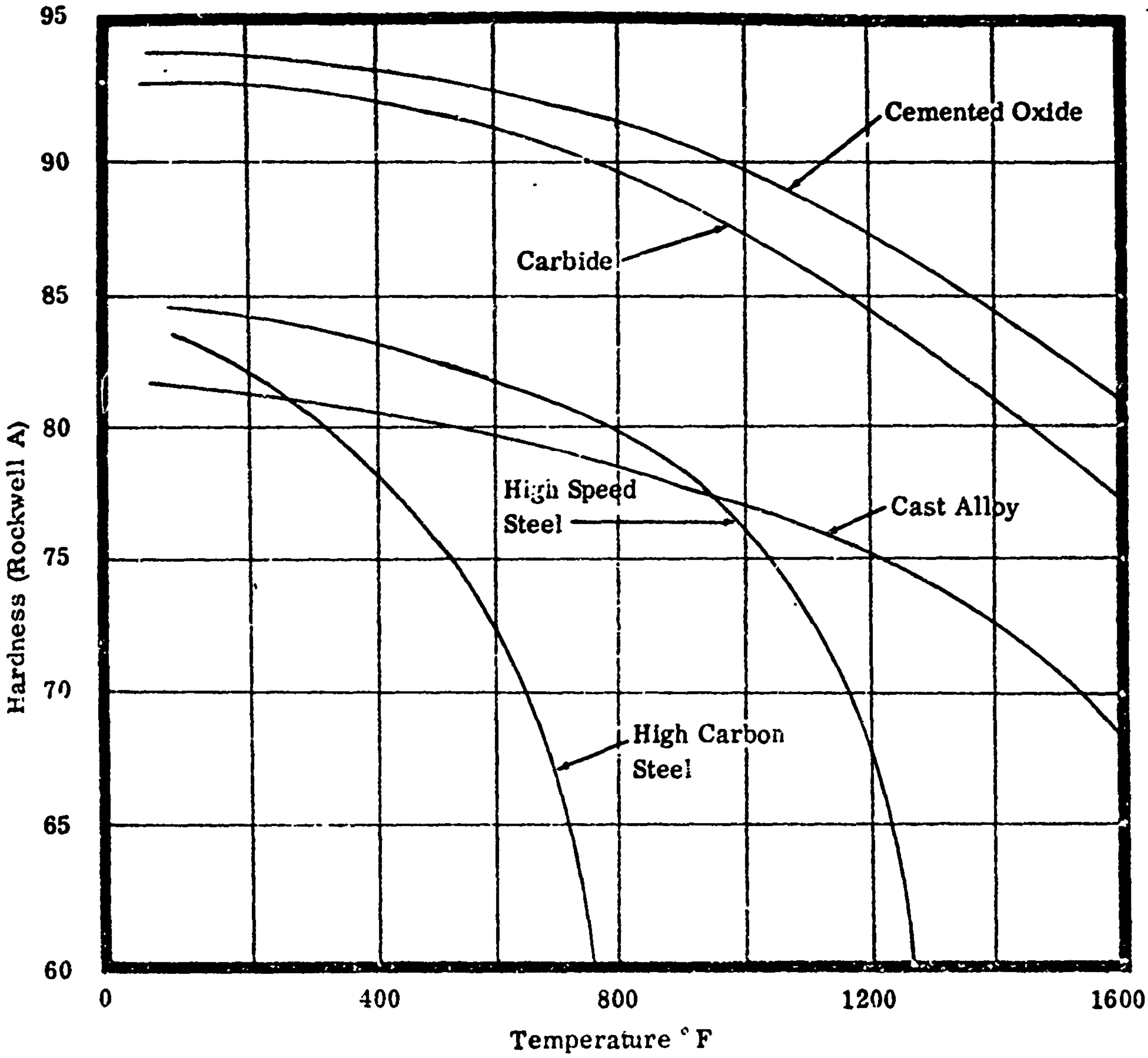


Figure 1 Hardness of Various Tool Materials at Elevated Temperatures. Relates Their Ability to Cut at Higher Speeds.

Figure 2

IDENTIFICATION OF CARBIDE CUTTING TOOL MATERIALS

	Application	Industry Code	Adamas	Carboloy	Carmet	Firth Sterling	Kenna Metal	New-Comer	Talide	Valenite	Vascoloy Ramet	Wesson	Willey
CAST-IRON, NON-FERROUS AND NON-METALLIC MATERIALS	Roughing	C-1	B	44A	CA-3	H	K6	NC-4	C-89	VC-1	VR54	GS	E8 E13
	General Purpose	C-2	A	883	CA-1	HA	K6	NC-3	C-91	VC-2	2A5 VR54	G1	E6
	Finishing	C-3	AA	905	CA-7	HE	K8	NC-2	C-93	VC-3	2A7	GA	E5
	Precision Finishing	C-4	AAA	999	CA-8	HF	K11	NC-2	C-95	VC-4	2A7	GF	E3
STEEL AND STEEL ALLOYS	Roughing	C-5	434	78B 370	CA610	TXH T-04	K21 K25	NS-3 NS-4	S-88	VC-5	EE VR77	WS	945
	General Purpose	C-6	D	370 78B	CA609	TXH TA	K3H K21	NS-3	S-90	VC-6	VR75	WM	710
	Finishing	C-7	C	78	CA608	T-16 TXL	K3H K4H	NS-2	S-92	VC-7	E VR73	WH	606
	Precision Finishing	C-8	66	350 330	CA605	T-31	K7H	NS-17	S-94	VC-8	EH	WH	509

ROUGHING	An extreme case of roughing cut, which involves interrupted cuts, chilled surfaces or similar complicating factors.
GENERAL PURPOSE	Initial machining operation involving the original surface of a bar, casting or forging: Removal of excess metal is the prime consideration.
FINISHING	The final machining operation to bring the part to blueprint requirements for size and finish.
PRECISION FINISHING	An exact final machining operation to produce surfaces to close tolerances, together with a fine finish.

NOTE: The above chart is not a grade comparison chart, nor is it an endorsement of any manufacturer's product or an approved list of services.

APPENDIX B

TOOL NOMENCLATURE

TOOL NOMENCLATURE

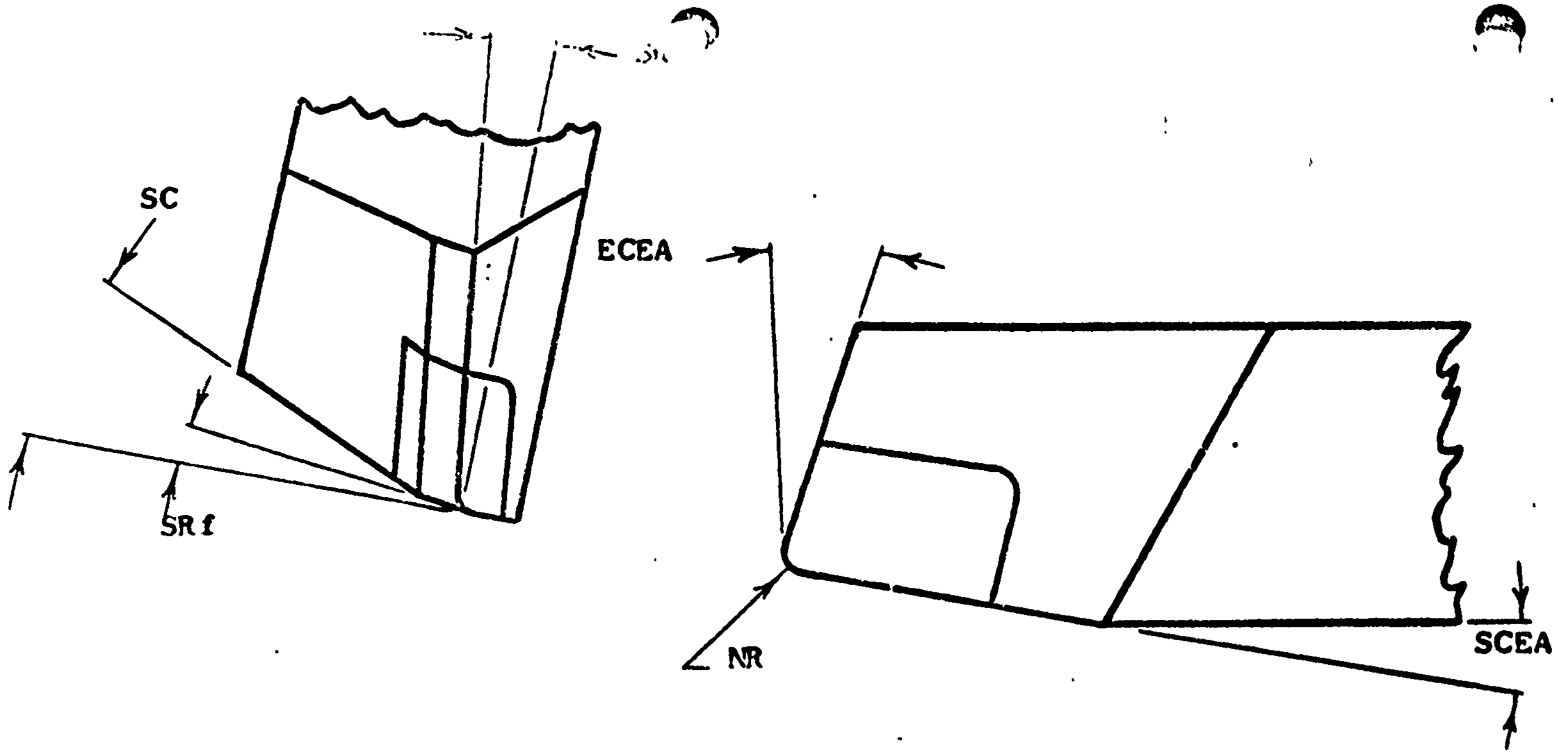
Before beginning any detailed discussion of tools, tool selection, and tool performance, it is well to have certain basic questions of nomenclature settled.

For carbide tools the part of the tool which is held in the machine and which supports the cutting edge is known as shank or body.

The cutting tool material is generally referred to as "tip" when brazed to the shank or body, and as "insert", when clamped to the shank or body.

Because of the many terms used to describe various aspects of cutting tools, a reference section is included which shows standard terms used through the industry.

Wherever possible the same nomenclature applies to the corrosponding point on all cutting tools, thereby eliminating possible areas of misunderstanding.



S.R. : SIDE RAKE (POSITIVE SHOWN)
B.R. : BACK RAKE (NEGATIVE SHOWN)
S.Rf. : SIDE RELIEF
E.Rf. : END RELIEF
SCEA : SIDE CUTTING EDGE ANGLE
ECEA : END CLEARANCE EDGE ANGLE
NR : NOSE RADIUS
EC : END CLEARANCE
SC : SIDE CLEARANCE

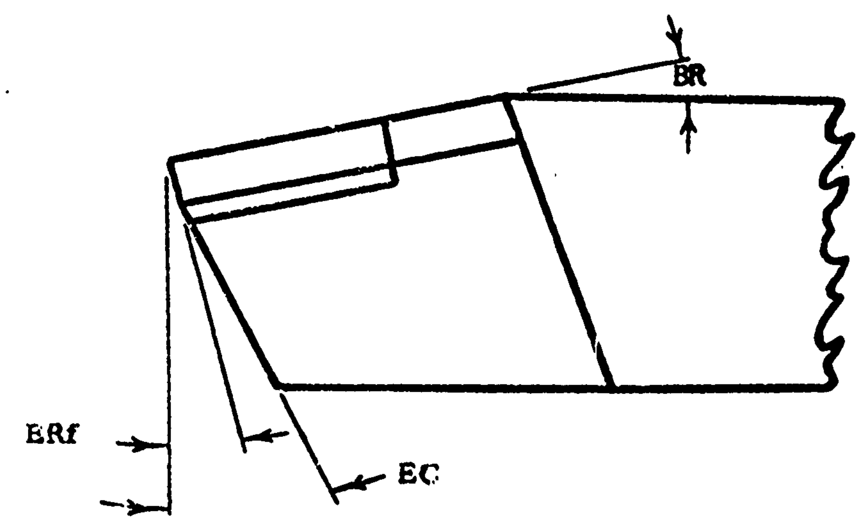
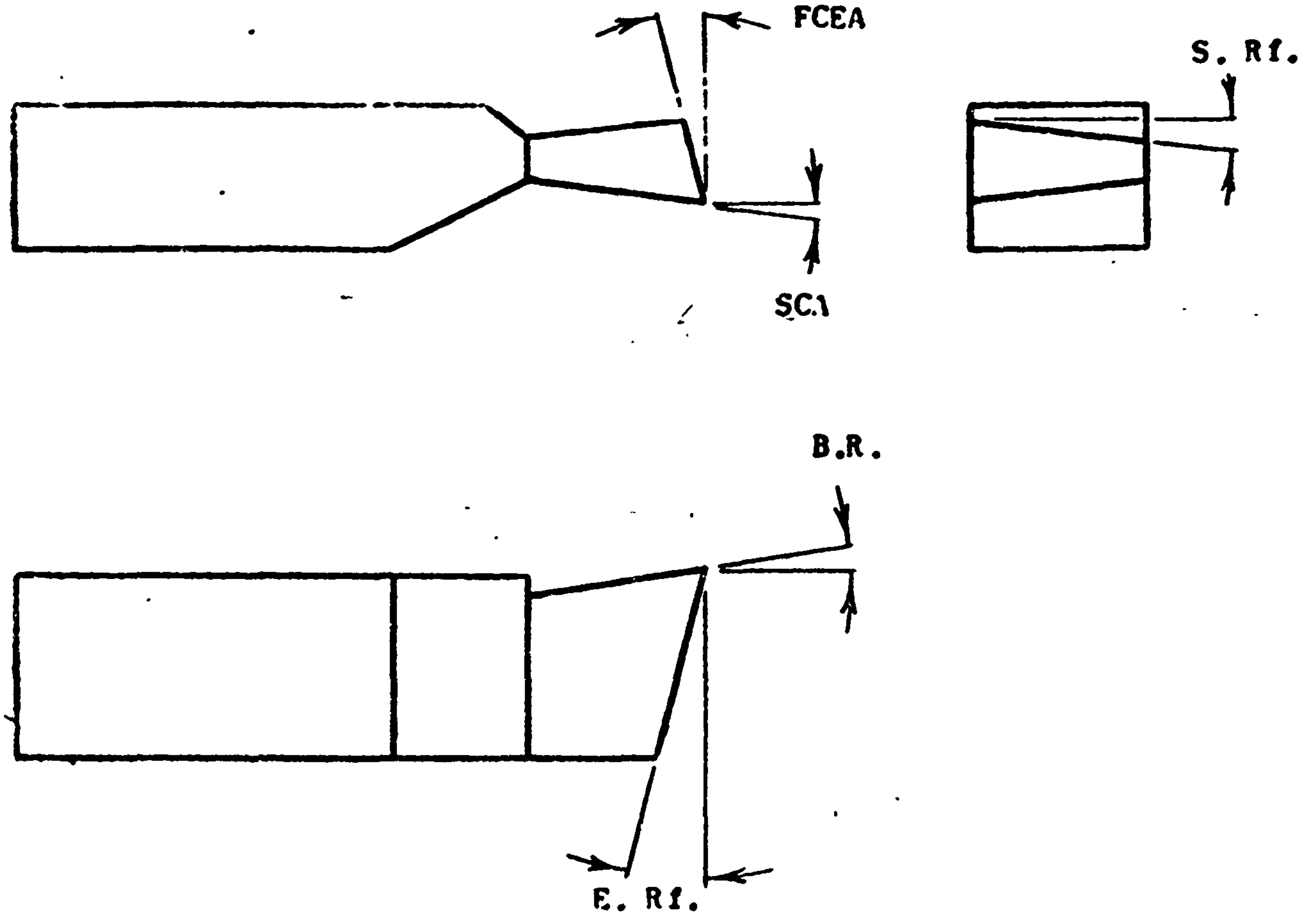
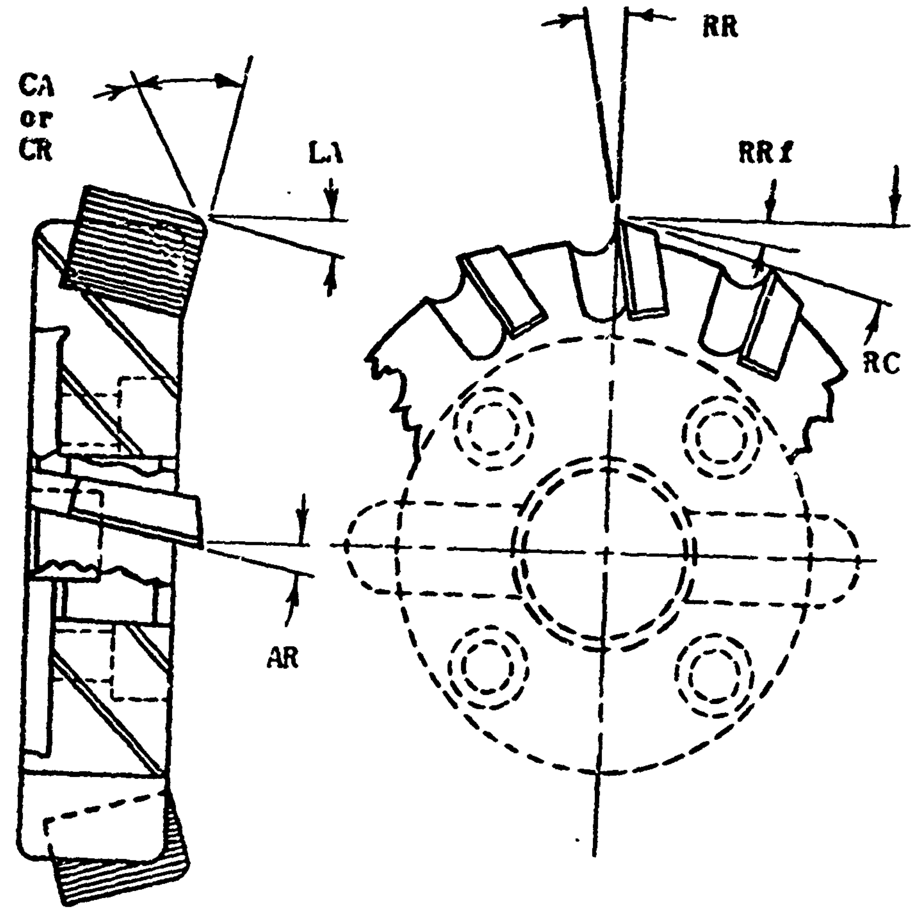


FIGURE 1 TOOL NOMENCLATURE FOR TURNING TOOLS



B.R.: Back Rake
S.Rf.: Side Relief
E.Rf.: End Relief
FCEA: Front Cutting Edge Angle
SCA: Side Clearance Angle

FIGURE 2 NOMENCLATURE FOR PLUNGE TOOLS



A.R. : AXIAL RAKE
R.R. : RADIAL RAKE
R.Rf.: RADIAL RELIEF
R.C. : RADIAL CLEARANCE
C.A. : CORNER ANGLE
or or
C.R. : CORNER RADIUS
L.A. : LEAD ANGLE
FCEA FACE CUTTING EDGE ANGLE

FIGURE 3 NOMENCLATURE FOR FACE MILLS

H.A.	:	Helix Angle
R.R.	:	Radial Rake
R.Rf.	:	Radial Relief
R.C.	:	Radial Clearance
E.Rf.	:	End Relief
C.A.	:	Corner Angle
		or
C.R.	:	Corner Radius.

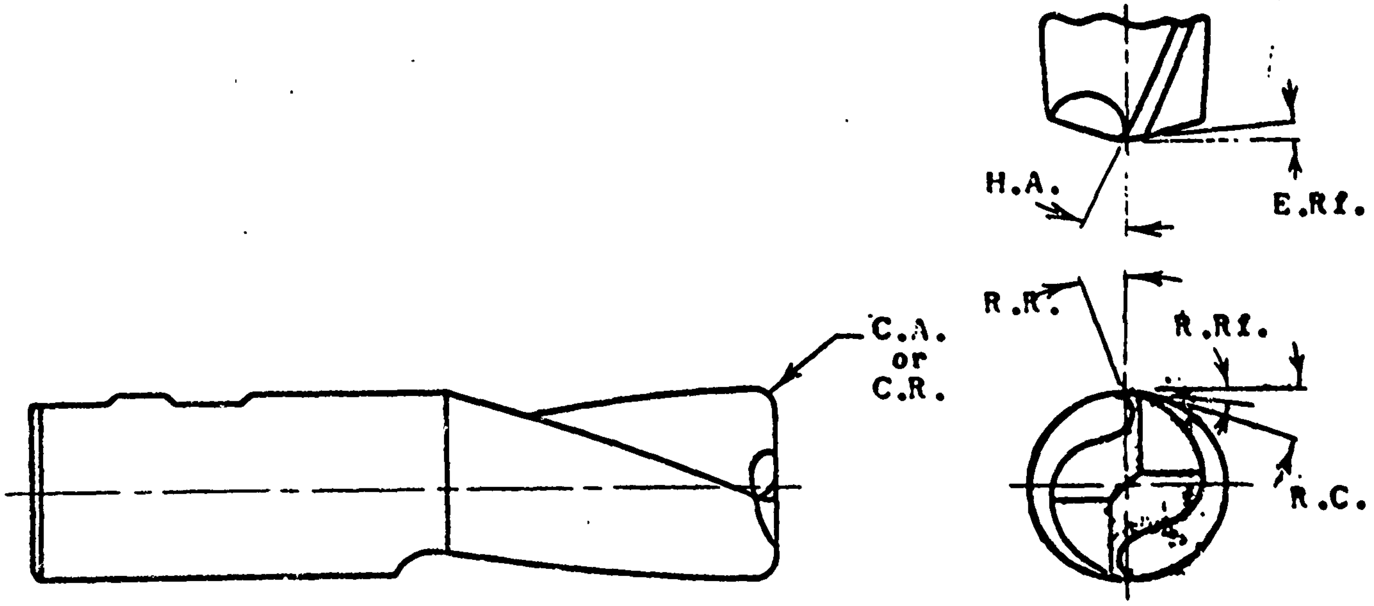
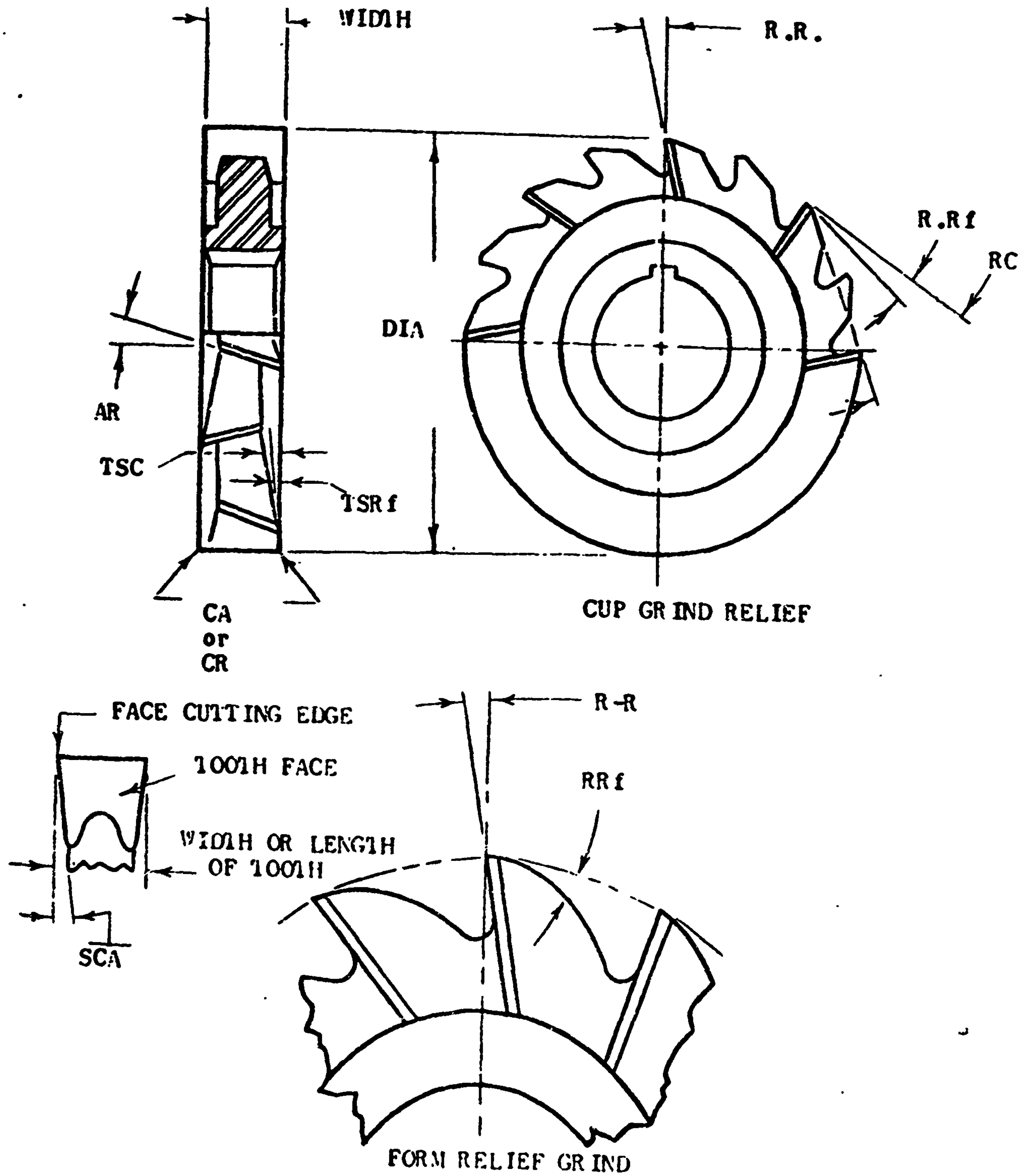


FIGURE 4 TOOL NOMENCLATURE FOR END MILLS



A.R. : AXIAL RAKE
R.R. : RADIAL RAKE
R.Rf.: RADIAL RELIEF
R.C. : RADIAL CLEARANCE
SCA : SIDE CLEARANCE ANGLE

T.S.Rf: TOOTH SIDE RELIEF
T.S.C.: TOOTH SIDE CLEARANCE
C.A. or C.R. CORNER ANGLE or CORNER RADIUS

FIGURE 5 NOMENCLATURE FOR STAGGERED - TOOTH SIDE MILLS

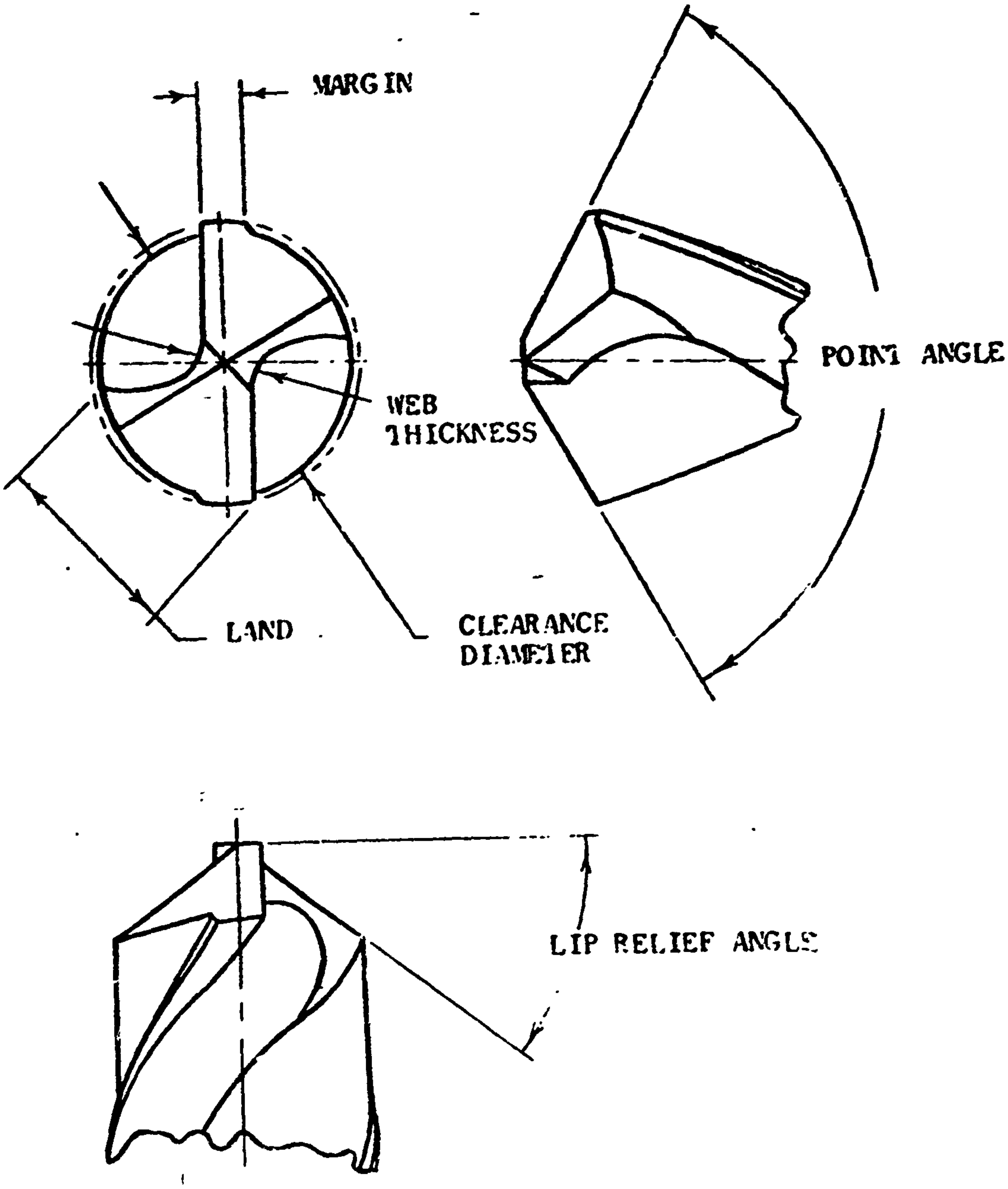
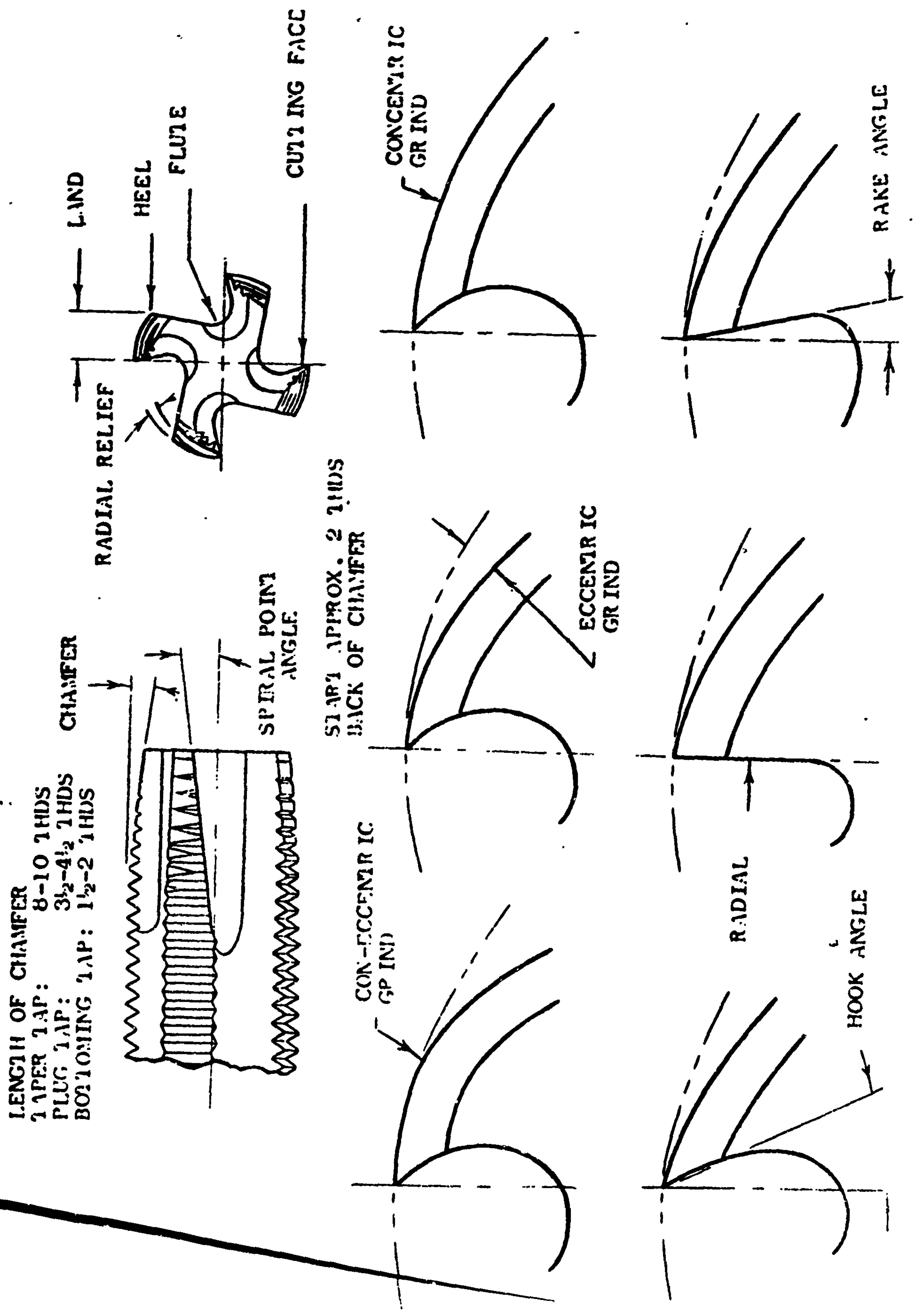
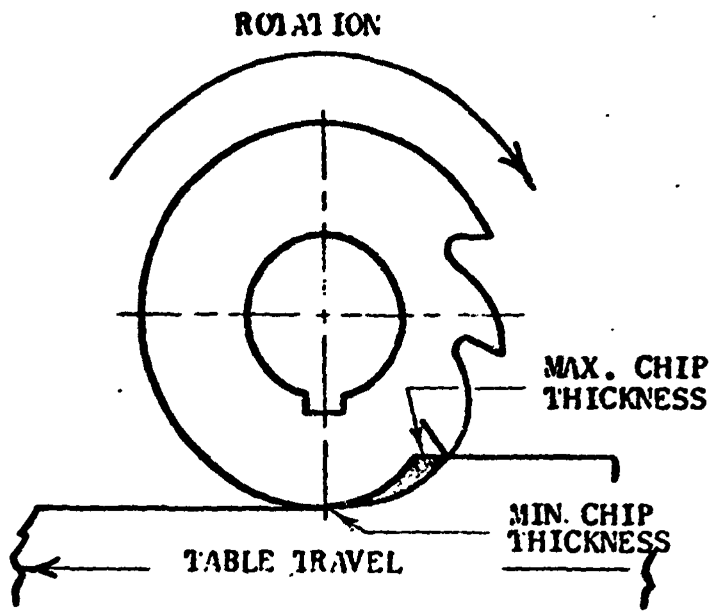
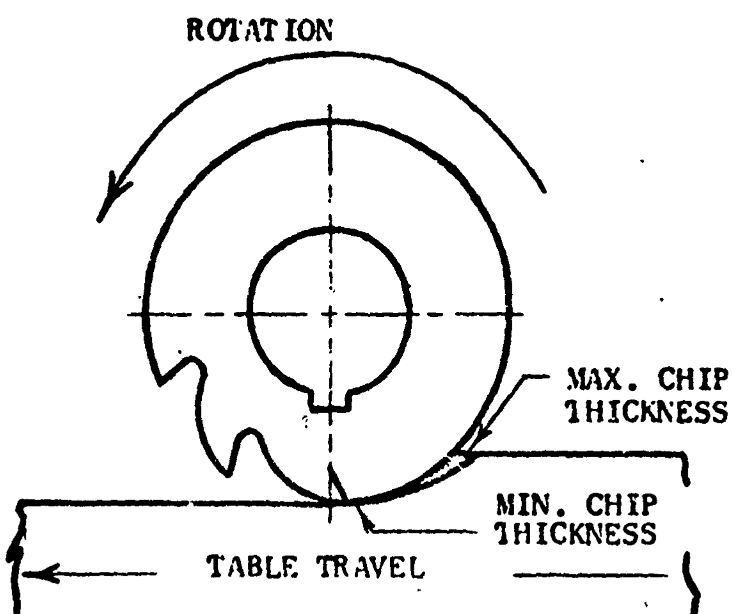


FIGURE 6 NOMENCLATURE FOR DRILLS


LAND
HEEL
FLUTE
CUTTING FACE
RADIAL RELIEF
CONCENTRIC GRIND
RAKE ANGLE
LENGTH OF CHAMFER
TAPER TAP: 8-10 THDS
PLUG TAP: 3½-4½ THDS
BOTTOMING TAP: 1½-2 THDS
CHAMFER
SPIRAL POINT ANGLE
START APPROX. 2 THDS BACK OF CHAMFER
ECCENTRIC GRIND
RADIAL
CON-ECCENTRIC GRIND
HOOK ANGLE



CLIMB MILLING



CONVENTIONAL MILLING

FIGURE 8 SIDE MILL CLIMB VS CONVENTIONAL

APPENDIX C

CUTTING FLUIDS

Because of the many variations in machining conditions, no attempt will be made to specify any particular coolant for specific application.

However, an attempt will be made to generalize the application of coolants in respect to work material, tool material, type of operation, cutting speed, etc.

There are two basic types of cutting fluids; water soluble oils or emulsions(including chemical coolants) and straight oils.

The primary purpose of the straight oils is to provide lubrication which reduces friction and heat during the cutting operation, while the soluble oils or emulsions are designed primarily as a coolant.

In general, the following rules for application of cutting fluids to machining operations will apply.

1 - Single point turning (Carbide) - Chemical or dry.

2 - Single point turning (H.S.S.) Chemical - oil

3 - Milling (Carbide) low alloy martensitic materials - dry

4 - Milling (Carbide) stainless steel, titanium and high temperature alloys - oil or chemical mist.

5 - Milling most materials (H.S.S.) Chemical

6 - Milling (Carbide) aluminum alloys - water soluble.

7 - Drilling - hard, tough materials - oil

8 - Drilling - aluminum, annealed low alloy steels - water soluble or chemical.

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